RESEARCH AND DEVELOPMENT BRANCH
DEPARTMENT OF NATIONAL DEFENCE
CANADA

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

DREO TECHNICAL NOTE 82-17

COMPUTER-AIDED DESIGN AT DEFENCE RESEARCH ESTABLISHMENT OTTAWA

by

D.J Hidson

PROJECT NO. 105

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OTTAWA

DEFENCE PURPOSE ONLY

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ABSTRACT

This paper describes the specifications for a computer-aided design and computer-aided manufacturing (CAD/CAM) system. A series of benchmark tests were performed with various vendors and on the basis of these results a system is recommended.

RÉSUMÉ

Ce rapport donne un compte rendue sur les normes utilisés à l'achat d'un système CAD/CAM (Design informatisé/ fabrication informatisée). Plusieurs essais sur place ont été éxécutés à différentes compagnies afin d'établir un choix d'un système répondant à nos exigences. Basé sur nos résultats, un système a été recommendé.

1. INTRODUCTION

Beginning in 1985, stocks of C3 NBC Protective masks held by the Canadian Forces will begin to expire and require replacement. The C3 mask, despite providing excellent protection, is based on an old design and does not meet the requirements in SOR(P) G1655, "Defence Against Chemical Warfare" and NATO AC 225 (Panel VII D/103). An improved design is required for the upcoming buy of masks.

Over the past several years, the US has been attempting to develop a new mask for their NBC requirements based on the use of advanced materials such as transparent silicone elastomers and polyurethanes.

The US development of the XM-29 ran into difficulties because of material supply problems, coating problems, distorted vision, poor liquid agent protection, and incompatibility with chemicals found in the military environment. As a result, the XM-29 was replaced by the XM-30. The XM-30 has the same configuration as the XM-29, the difference being that the facepiece and visor are molded separately. The visor is made from a flexible urethane material, while the facepiece remains silicone elastomer. These modifications only overcome a portion of the difficulties encountered with the XM-29 design. As a result, few observers within DND are optimistic that the present US program will result in a mask that will meet Canadian requirements.

Canada has agreed to develop a canister for the US XM-30 mask. Under the terms of the memorandum of understanding, between the US and Canada, the US will make a small initial purchase of canisters from Canada, after which Canada will compete with US industries for further orders. In return, provided the XM-30 meets Canadian requirements, Canada has the option of setting up its own assembly line for production of the XM-30 after making its initial buy from the US. The Canadian mask requirement would make it unlikely that an assembly line in Canada would be profitable.

As a result of this, an exploratory program was set up at DREO to investigate the difficulties of designing and producing a new mask in Canada. The old manual method was assessed in the light of current personpower and funds. In the time-frame available this method promised very little hope of being able to produce a mask that would be

adequately engineered and tested. Because of these considerations, computer- aided design and computer- aided manufacturing systems were investigated in detail with a view to producing a prototype mask with this method. The following paper describes the former method of manufacture of masks with particular attention to personpower and time constraints; a description of several computer- aided design and manufacturing systems; and analysis of bench mark tests carried out at two contending vendors.

2. MASK DEVELOPMENT AND DESIGN

2.1 MANUAL DEVELOPMENT METHOD

The manual development method refers to the method of making and developing masks that has been used in the past and up to the present time. This process is carried out in several steps.

The designer begins the process by making preliminary sketches of design concepts for the mask. These lay out, in general, the shape and position of the visor, canister mounts, speech transmitter and valving system. However, to define the complex, compound curves found on the face-piece by manual means on a set of drawings is next to impossible. The best that can be accomplished is to provide the model-maker with an artistic representation of the concept with the general position of the components specified.

The drawings and sketches are then passed to the modelmaker who selects standard headforms representing small, medium and large sizes of the population to be fitted by the mask. The model of the mask shape is built up from a Plasticine material or modelling clay so that the ideas may be viewed in three-dimensions. Changes are made until the designer is satisfied with the shape of the mask. At this point, little data is attainable from the model. Changes are made on the basis of what appears right. This step in the development process is an attempt to ensure that the designer and model- maker have the same shape in mind.

The model-maker must construct a mold that will produce a mask in the shape of the Plasticine mock-up. The mold is constructed from plaster and the mask is cast in a silicone elastomer which vulcanizes at room temperature and low pressure. The various plaster pieces which make up the mold (an early concept was cast in a mold consisting of seven pieces) must themselves be cast over a pattern or in a mold carved out of a solid block. This work is all carried out by hand.

The construction of the plaster mold is the most time-consuming phase because of the handwork involved. Dimensional control between the Plasticine- model phase and the plaster-mold phase is very poor. While the plaster mold is being made, it is difficult for the designer to control the shape of the mask that the mold will produce.

An evaluation of the design can begin only after the completion of the plaster mold. Due to the large amount of handwork involved, the process from the issue of sketches to the completion of the plaster mold may take seven to nine months. Any modifications to the design or alternate designs would require a similar length of time. Optimization of design is thus seriously limited. The plaster mold is the only record of the mask design and is very fragile and delicate. Only a limited number of masks can be constructed because of the risk of breaking the mold while removing the cast facepiece.

Once the designer is satisfied with the shape of the mask, the plaster mold is duplicated in steel and a mask can then be molded using the proper materials. The accessories can then be mounted and the mask evaluated more fully.

With this manual design process there is approximately a seven-month waiting period before a design can be evaluated with design iteration requiring a similar amount of time. Very little evaluation can occur before an actual three-dimensional mask can be constructed. Thus it is not a very practical method for producing an optimized design.

What is required for such a project is a method of handling complex geometrical designs and translating these designs into real three-dimensional objects. Such a method involves the use of a computer-aided design and computer-aided manufacturing system.

3. COMPUTER-AIDED DESIGN AND COMPUTER-AIDED MANUFACTURING

3.1 CAD/CAM

CAD/CAM is an acronym for computer-aided design and computer-aided manufacturing. The CAD part of the process enables the designer to view a computer-generated picture on a screen (usually a cathode-ray tube) of the object he or she is working with. The designer can manipulate the display using an electronic stylus, alphanumeric keyboard or digitizing tablet. The maturity of the advanced systems

allows this to be done without specialized programming languages.

The CAM portion of CAD/CAM allows the designer to use the data base describing the object designed as a data base for computer-driven machining tools. Once an image is stored in the machine memory as a series of numbers, the next logical step is to produce a program for a numerically-controlled milling machine (NC machine) to cut the part directly without the need for human intervention. Thus a fully computer-aided process allows design to be carried through from conception to manufacture.

3.2 APPLICATION OF CAD/CAM TO MASK DESIGN

The advantages that a CAD/CAM system offers the problem of mask design are considerable. The surface of a mask may be completely defined by an array of x-, y- and z-coordinates. Modifications to the model require only that the coordinates in the area of interest be changed -- an easy and rapid task.

The design of the facepiece geometry begins with the development of digitized faceforms modified to represent the required anthropometric data as accurately as possible. Once this has been done, individual mask hardware units such as the speech transmitter and canister mounts may be designed and positioned in front of the faceform. These units could be re-positioned at will until their optimum positions were discovered. The visor would be designed in the same fashion so as to provide maximum field of view. Data for variables such as the clearance of the visor over the combat spectacles can be determined quickly. The facepiece periphery can then be designed and the surfaces connecting the hardware units (the non- critical areas of the facepiece) are added by surface-matching subroutines. Once one size has been designed, the other sizes may be produced by scaling the model in various ways.

When the design is completed, many engineering tests can be performed on the graphics terminal before the molds for the mask are constructed. Most of these tests can be performed very quickly. The CAM part of the system can be brought into play to manufacture the metal molds required to build prototype masks. Using the data base of the computer-generated model as a source for a control program for a numerically controlled milling machine, such a program is written automatically. The core and cavity are cut precisely corresponding to the shape of the designed object.

Much time and a great deal of versatility is gained by using this type of approach to the complexities of mask design. The designer has control over all the design process. There is no need to communicate a complex design shape by imprecise means the design is always as accurate as the data base. Major changes may be made and retested in a matter of hours and days rather than weeks or months. There is no handwork involved and no chance for errors and variations in shape to creep in. Molds are made by NC machines which eliminate the need for intermediate plaster molds - fragile and seldom accurate.

4. CAD/CAM SYSTEMS AND SPECIFICATIONS

CAD/CAM systems can be one or two types: turnkey or time- sharing.

A turnkey system is a self-contained CAD/CAM system consisting of computer hardware, software, graphics terminal, digitizer and other accessories deemed necessary and useful.

A time-sharing system consists of on-site graphics hardware: storage tube CRT or refresh graphics work station, digitizer, hard-copy unit and/or plotter connected to an off- site central computer where the software is resident. In this option, the software is leased.

These two approaches each have their own advantages and disadvantages.

Turnkey systems are self-contained and are the property of the buyer. Costs are basically fixed at the purchase price which may be fairly high. Thereafter there are no further costs regardless of how much the system is used.

Time sharing systems enable the user to spend less money on hardware. The disadvantages here is that rented computer time and leased communication lines are continuing costs and a function of the hours of usage. However, changes and upgrades in software packages resident on the host computer are passed on to the user.

An examination of the requirements for DREO in terms of costs, availability of systems, and project time-frames, was conducted and the following requirements list was drawn up.

Commercial and support aspects:

1. Current commercial availability;

2. Fully debugged software with proven reliability;

3. Trained and experienced support staff with engineering design experience on the system;

4. Ability to discontinue service without a large penalty;

5. Low capital expenditure;

6. Competitive costs.

Engineering, Interaction, I/O, storage aspects:

7. High interaction rate;

8. 9600 baud minimum communication rate;

9. Real-time interactive graphics;

10. Efficient use of menus and their hierarchies;

11. No specialized programming languages;

12. Human engineering in hardware and software;

13. On-site plotting;

14. Capability to produce magnetic or punched tape for NC machine use;

15. Capability to produce magnetic tapes of data files;

16. Input data via punched tape; magnetic tape, keyboard, digitizer or electronic stylus;

17. Reliable archival and on- line storage;

Software aspects:

18. Fully three- dimensional operation;

19. Methods of entity generation;

20. Functions including cubic splines; parametric ruled surfaces, surface generation, etc;

21. Grouping of entities;

22. Rotation about arbitrary axes in world coordinates;

23. Translation along arbitrary axes;

24. Mirroring;

25. Unidirectional scaling;

26. Omnidirectional scaling;

27. Replication of entities;

28. Viewporting;

29. Multiple viewing;

30. Projections and perspective;

31. Sectioning;

32. Analysis including linear, angular, positional, sectional, surface and volumetric properties;

33. Kinematic analysis;

34. Automatic part dimensioning;

35. Engineering drawings to standards;

36. Integrated NC package with a capability to generate NC programs automatically for a large number of NC machines.

This was used for preliminary screening when investigations of commercial CAD/CAM systems were undertaken. Several systems were not investigated beyond a preliminary phase as they failed to satisfy some of the major requirements set out above. The following companies were investigated.

* Hewlett Packard
* California Computer Products
* Information Display Inc
* Tektronix
* Evans & Sutherland
* Vector General
* Phoenix Graphics Ltd
* Control Data Corporation
* Applicon Inc

* Auto-trol Technology Corporation
* Calma
* Compeda Corporation
* Gerber Systems Technology
* Data Technology Inc
* Computer Operations Inc
* National Computer Systems
* Digital Equipment Corporation
* Perkin-Elmer
* ComputerVision Inc
* Summagraphics
* Prime Computer Inc
* IBM
* Xytech
* Xycom
* Human Computing Resources
* Martec Ltd
* Manufacturing and Consulting Services Inc
* MCAUTO

A majority of these companies offered only turnkey systems and a majority of those turnkey systems were discarded because they involved excessive capital expenditure. Many others simply did not have the geometric modelling capability that is required. The final choice was to be between Control Data Corporation and McDonnell Douglas Automation Company (MCAUTO), both offering time-sharing computer services. In order to gain a firm idea concerning the respective system capabilities, benchmark tests were devised and carried out at the headquarters of the prime contenders - Control Data and MCAUTO.

Control Data markets an interactive CAD/CAM system, CD/2000, which is the successor to AD-2000. AD-2000 was operated under licence from Manufacturing and Consulting Services Inc in the US.

CADD ("caddy"), or Computer-Aided Design and Drafting, is a time-sharing system marketed by MCAUTO. To perform these tests, a visit to Control Data Headquarters in Minneapolis and MCAUTO in St Louis, was arranged. One and one-half days were spent at Control Data and one day at MCAUTO.

5. BENCH MARK TESTS

5.1 PROBLEM DESCRIPTION

These tests were designed to obtain a more acccurate idea of the operating costs and technical prowess of the

two systems.

Two problems were selected and sent to both Control Data and MCAUTO one week ahead of the visit to allow each company a preliminary discussion about how best to tackle the problems.

These problems are shown in Figures 1 and 2. Figure 1 is referred to as the complex curve problem and figure 2 as the drafting problem.

Figure 1 represents a cover for a machine housing to be made from plastic of thickness 0.063 inch. The required information is:

1. Two or three isometric views of the finished product;
2. The volume of material in the cover;
3. The volume contained by the cover;
4. The inner and outer surface areas;
5. An NC tape to cut a mold for the cover;
6. The weight of material used in the cover given a density of 0.035 lb/cubic inch.

From figure 2, the required information is:

1. Fully dimensioned drawings;
2. An NC tape.

5.2 COMPLEX CURVE PROBLEM

5.2.1 CADD

5.2.1.1 OBJECT DESIGN

The design session at MCAUTO was arranged to correspond as closely as possible with the conditions that would pertain at a MCAUTO CADD work station set up at DREO. As the computer facility at MCAUTO was in the process of being transferred to new buildings at the time of the visit, one condition was different: the communication line between the Tektronix terminal and the main-frame computer was 4800 baud, slower than the 9600 baud planned for our use. If

anything, the design times at the terminal are an overestimate.

The ellipsoids, elliptical cylinders and the variable elliptical cylinder were generated using the point, function and autogroup operators on CADD. The axes of these shapes were stretched in one or two dimensions independently to match the exact size shown on the drawing. These curves were then surfaced with three-dimensional splines completing a mesh over the curved end-surface. This was then mirrored about a plane of symmetry through the object. This designed work was performed in the trimetric (approximately isometric) view in full 3-D. The surfaces were then offset by 0.063 inch along the direction of their surface normals and the inner surface defined. The time for this operation was 2.15 hours. This included some duplication for the sake of clarity and explanation. This also included, also fully automatically, side, plan, elevation and trimetric views, all surfaces area and volumetric properties, thereby satisfying five of the six requirements (see Figures 3-10). Those Figures shown with the function diagram in the corner are hard-copies of the Tektronix 4014-1 screen display taken with the Tektronix hard copy unit.

5.2.1.2 NC CURVE GENERATION AND TAPE PREPARATION

The NC portion of the problem required the generation of cutter paths to produce a cavity from a solid block of material which could be used for forming the object. Paths were generated first for the elliptical surfaces in 0.1-inch increments. This resulted in twenty passes around this surface with a one-half inch cutter. The surface tolerance required was 0.001 inch. NC machine information is produced on a printout as the job is submitted to batch. Cutter paths are shown in Figures 11 and 12.

The cavity was finished off by generating a set of curves to cut the slanted planes and the cone/edge corners of the object. Again, twenty passes of the cutter were chosen and a smaller cutter diameter chosen to accomodate the smaller radii of curvature of the corners. This was then added to the curve/ellipsoid part of the complete job.

5.2.1.3 COSTS

MCAUTO evaluates its computer resource units for its customers as VRUs, a combination of CPU times, I/O events

and storage. These are billed to the user at the rate of $10.00 per VRU in prime time (8.00 am to 5.00 pm St Louis time) and $5.00 per VRU in any other time period. This session used 47.59 VRU, but a streamlined session could have completed the design with approximately 35 VRU. The cost for the design time was $476. All costs are summarized in table A. The cost for the design and the NC curve generation and tape preparation was $670 and the cost-effectiveness factor expressed as a product in dollar-hour units (the product of dollars and hours) was 1997 $h, where $h represents one dollar-hour. The smaller this number, the greater the cost effectiveness. This assessment is predicted on the passenger-mile concept used by commercial airlines.

MCAUTO also performed the complete geometry operation on the Distributive Graphics System (DGS) with Evans and Sutherland picture terminals in 0.45 hour using 7.38 VRU. This results in a cost of $74 and a cost-effectiveness factor of 33.21 $h compared to 1023 $h for the same job on the Tektronix terminal.

5.2.2 CD/2000

5.2.2.1 OBJECT DESIGN

CD/2000 was unable to solve this problem but Control Data presented their method of tackling it in a memorandum to DREO. First, lines bounding the planes were entered. Second, the complex curved side was considered. Here, analytical equations for the ellipsoidal surfaces were set up using the data from the drawings supplied. Then a FORTRAN program, with more than 150 lines of code, was written to generate points on the surfaces: these points were used as control points for spline curve generation. An unsuccessful attempt was then made to join the points in spline curves to form a surface. In the course of 1-1/2 days at Control Data Heaquarters, this was as far as the problem progressed. Displays may be seen in Figures 13-15.

This problem demonstrated several serious shortcomings with the design capability of CD/2000.

A long FORTRAN program had to be written to input data points which described the elliptic surfaces (see figure 13). Had there been no analytical description of the surfaces, even this would have been impossible. This data was input into the machine via the bulk input mode.

In order to generate 2-D spline curves in the xy-, yz- or zx- plane, the object has to be displayed with one of those planes normal to the screen. A view was displayed with one of those planes normal to the screen. A view was displayed in the yz-plane and 2-D spline curves generated and, by connecting the data points, the process repeated in the zx-plane. This resulted in sets of 2-D spline curves defined in orthogonal planes. Although the object could be viewed in an arbitrary trimetric view, no design work could be performed on it when it was so displayed. These splines in the yz- and zx- planes could not be joined to form a surface in three dimensions. The final position is shown in figure 15.

5.2.2.2 NC CURVE GENERATION AND TAPE PREPARATION

No curves were generated and no NC tapes produced.

5.2.2.3 COSTS

No cost estimates were presented by Control Data for this problem.

5.3 DRAFTING PROBLEM

5.3.1 CADD

5.3.1.1 OBJECT DESIGN

MCAUTO completed this design in 0.47 hour and with 10.00 VRU of computer resource units. The design functions were elementary, and a fully dimensioned drawing produced automatically with any desired layout of text and numerals. The cost-effectiveness factor was 47 $h. For a display see figure 16.

5.3.1.2 NC CURVE GENERATION AND TAPE PREPARATION

This took 1.57 hours of design time at the terminal using 38.9 VRU. The cutter paths are shown in the trimetric configuration in figure 17.

5.3.1.3 COSTS

The time for whole design job was just over two hours generating a cost of $489. The cost-effectiveness factor worked out to be a 997 $h.

5.3.2 CD/2000

5.3.2.1 OBJECT DESIGN

CD/2000 was able to handle this problem satisfactorily. The design was carried out with CD/2000 on the KW1 operating system using a 1200 baud dial-up telephone line with micro-assist.

The geometry input took 1.25 hours and the drafting (dimensioning, sectioning etc) 3.1 hours. This part of the job was completed with dimensioned drawing. A sample of the results is shown in figure 18.

5.3.2.2 NC CURVE GENERATION AND TAPE PREPARATION

NC curve generation took 1.5 hours using point- to-point drill and pocketing. The NC paths are shown in figure 21: no details on the cutter size and/or tool changes were provided. Some surface area and volumetric properties are shown in figure 19.

5.3.2.3 COSTS

The total time for this job was 6.13 hours at a cost of $670 giving a total dollar-hour rating of 4113 $h.

5.4 PROBLEM SOLUTIONS

5.4.1 CADD AND CD/2000 COMPARED

MCAUTO produced solutions using CADD to both bench mark problems complete with time and cost analyses with all requirements satisfied. Control Data's CD/2000 produced a satisfactory answer to the drafting problem but was unable to solve the complex curve problem.

CD/2000 has several severe deficiencies in comparison to CADD.

It is not possible with CD/2000 to work in the trimetric view. Data must be input when viewing the design object from the side, plan or elevation. A trimetric view may be obtained but, when displayed, can only be rotated in relation to screen co-ordinates and not to the model co-ordinates. In any event design data from the digitizer or keyboard cannot be entered in this mode.

The data for the complex surfaces was entered in function form by CADD in approximately one-half hour. Elliptic axes were defined, stretched or contracted along the x-, y- or z- axes to define the curved end surfaces. These were then mirrored about the plane of symmetry and the edges joined up to create the outer surface of the object. It appears that the software comprising CD/2000 is just not capable of this kind of operation: handling complex 3-D patch surfaces in 3-D.

As a result of this, CD/2000 was also unable to produce any of the surface area and volumetric quantities as the data points generated by the FORTRAN program were never defined as a surface.

Spline curves, essential for construction of surfaces without analytic, functional definition, are only operable in 2-D in CD/2000 but are fully 3-D in CADD. The union of spline curves in all three dimensions is essential for arbitrary patch surface definition and the manipulation of 3-D entities. (An entity is an arbitrary combination of patch surface elements).

The drafting problem was successfully completed by both systems but was really only a 2-D problem. CADD still produced a faster and cheaper solution to this problem, taking two hours and $489 as opposed to more than six hours and $671 for CD/2000.

5.5 SYSTEMS OPERATION

5.5.1 CADD

MCAUTO is a subsidiary company of McDonnell Douglas Corporation. It markets a complete 3-D interactive graphics package, CADD, along with many varieties of CAM. The hardware basis of this system is in MCAUTO's headquarters in St Louis, Missouri, and is the largest facility of its kind in the world. CADD was originally developed by MCAIR, McDonnell Douglas Aviation Company, for use in engineering and aircraft design, but not long after the introduction of the system it became very successful and was marketed commercially in its own right.

When CADD is operational it uses the MCAUTO TSO (Time- Sharing Option). It is accessed via a communication line to the facility in St Louis. In CADD, an exact mathematical description, or 'model', is stored in the machine memory. The representation of this model on the screen may be in the form of a completely surfaced 3-D model; a 3-D wire-frame structure; or a 2-D wire frame (see illustrations in the Appendix). Any one of these three can be used to create and display the other two. Engineering drawings, NC tapes, surface area and volumetric properties of any design, may all be produced on request by simply calling a menu command. Since CADD is leased to the user, modifications become available to all users.

Within the time-sharing option there are two terminal options available. These differ in capital cost, overhead and versatility. They are termed the Distributive Graphics System (DGS) and the Nondistributive system and are illustrated in a block diagram in figure 20 of the Appendix.

In the Nondistributive option, the hardware purchased consists of a Tektronix 4014-1 terminal, hard copier, digitizing tablet, Calcomp plotter and modem. The screen operates in storage mode. All changes to the model data base must be transmitted through the communication line to St Louis for processing in the host computer. This includes all such operations as rotations, translations, deletions, re-painting of display etc. All manipulations are handled by the host computer and a charge is recorded for the time used.

In this option, a set of function keys is displayed in the top right-hand part of the Tektronix screen. When the user wishes to perform an operation e.g. create a line, section, surface, arc etc. he touches the electronic stylus of the image of that particular key on the screen. If further information is required to perform the action, then

the menu prompts by supplying choices which are displayed in the bottom part of the screen. When the information requirements are satisfied, the command is executed and the new data e.g. line, arc etc are painted on the screen. All this is processed by the host computer.

The display can become quite complicated. In order to make changes to the display, such as erasing surfaces, or viewing from a different point, the whole picture has to be erased and re- painted with the new specifications supplied through the function keys before the re-painting commences.

In the DGS system, the hardware required is an Evans and Sutherland Picture System 2 (2 picture tubes and an Evans & Sutherland Picture Controller), a DEC PDP 11/70 minicomputer and a Calcomp plotter. There are several major differences between this and the Nondistributive system:

(1) The Evans & Sutherland picture tubes operate in refresh mode;

(2) The graphics functions (eg translation, rotation and zoom of the model) are performed in real-time, locally, by the software on the PDP 11/70;

(3) Clipping planes allow the display of only a portion of the model between the planes;

(4) Less host computer CPU time is used.

DGS differs from the non-DGS in this manner: the function key display is a real, physical push-button keyboard. The E & S terminals, which operate in refresh mode, are re-painting the display sixty times a second. In addition to the function keyboard, the DGS system has a second keyboard containing the functions axial rotation (pitch, roll and yaw), scale, clipping planes and translation. These operate as analog functions: continuous rotation of that particular function button will produce continuous operation of that particular function e.g. continuous rotation of the button labelled 'Axial Rotation z/yaw' will produce, on the screen, in real time, continuous rotation of the displayed model about its z-axis. The use of a combination of clipping plane and translation can generate a 'walk-through' of a three-dimensional model in order to show its internal structure plane-by-plane.

The 'Scale' button produces an effect similar to the zoom lens on a camera, expanding and contracting the image according to the direction of rotation of the control button.

The versatility of this method of control means that the computer model can be handled on the screen as if it were a solid, three-dimensional object. Entities can be defined, moved around and re-oriented on the object at will. Again, this is done manually in real time in contrast to the nondistributive system which requires the decisions on position, orientation etc to be completed before any repainting of the picture is performed.

5.5.2 CD/2000

With the Control Data package, CD/2000, the hardware required is a Tektronix 4014-1 storage tube and a telephone modem connected to a 1200 baud dial-up line to Control Data's CYBERNET network. This is a very much slower communication line and would add significantly to design times because of excessive picture re-paint times. Further, analog telephone lines are more prone to error insertion in the signal. With the large amounts of data generated by interactive graphics, this may be another problem. 1200 baud communication lines are contra-indicated by many graphics users, including MCAUTO.

On-site plotting is not possible with this arrangement over CYBERNET: this will only be possible with a 4800 or 9600 baud dedicated communication line and this system is not due to be introduced until late 1982.

During the operation of CD/2000, feedback commands or prompts are displayed on the screen, in scroll fashion, obscuring the picture. With the addition of a CDC 722 terminal and a graphics terminal microprocessor assist, GTA, the prompts may be displayed on the CDC 722 and thus leave the drawing uncluttered and legible. This, however, divides the operator's attention between a digitizer, for some function input, the keyboard, for most of the input and commands, the screen displaying the prompts, and the display on the storage tube.

CD/2000 was not developed by Control Data, but is a modification of AD-2000 operated under license from Manufacturing and Consulting Services Ltd. Originally titled AD-2000 the name has been changed and some modifications made to the software.

NC paths may be generated on the model, but NC tape preparation is not an integral part of the CAM portion of CD/2000 and there are no readily available post-processors to be called up for finished NC tape production.

5.6 CONCLUSIONS FROM BENCH MARK TESTS

Two problems, one involving complex surfaces and the other a simple drafting problem, were presented to Control Data Corporation to be solved on CD/2000 and to MCAUTO to be solved on CADD.

CD/2000 could not solve the complex surface problem because of significant shortcoming in working in 3-D. CADD had no difficulty solving either problem.

Although the operating costs for CD/2000 work out to be approximately $137 per hour, the six hours required for the drafting problem was three times longer than required by CADD.

Operating costs for CADD could be higher than previously estimated, but not significantly so. Although Control Data's estimates were also higher than their previous projections, the time required to perform a simple job was much longer than that required by CADD. If assessed in a dollar-hour product space, CADD is more than four times as cost-effective as CD/2000 even on the basis of a simple problem.

6. SUMMARY AND RECOMMENDATIONS

The main problems of the current engineering work on mask design have been discussed. These are:

* dimensional control problems
* product scheduling
* design optimizing problems
* reproducibility

A study of commercially available CAD/CAM systems revealed that only one system is really satisfactory for engineering design and has the capabilities of addressing complex problems inherent in the mask program, not the least of which is the completion of a fairly large project, up to the stage of production engineering, in a relatively short time.

CADD is well-suited to handling engineering design work as considerable thought has also been brought to bear on the human engineering side of the CAD/CAM work environment.

The productivity gains which can be realised with the use of this system are:

* 8:1 in product development
* 4:1 in drafting
* 10:1 in tool design
* 6:1 in NC machine programming

Of all the systems considered, only the MCAUTO system has the capabiliy, versatility and availability to present a viable solution to the various problems facing mask design. MCAUTO CAD/CAM is recommended for DREO.

TABLE A

CAD/CAM BENCHMARK TEST AT
CONTROL DATA AND MCAUTO

FUNCTION	MCAUTO	CONTROL DATA	MCAUTO: CONTROL DATA
1. COMPLEX CURVES			
1.1 COMPLETE GEOMETRY (TEKTRONIX TERMINAL)			
TIME	2.15 HR	N/A	N/A
COMPUTER UNITS	47.6 VRU	N/A	N/A
COST	$476	N/A	N/A
COST-EFFECTIVENESS	1023 $HR	N/A	N/A
(DGS: EVANS & SUTHERLAND PICTURE SYSTEM)			
TIME	0.45 HR	N/A	N/A
COMPUTER UNITS	7.4 VRU	N/A	N/A
COST	$74	N/A	N/A
COST-EFFECTIVENESS	33.2 $HR	N/A	N/A
1.2 NC CURVE GENERATION AND TAPE PREPARATION			
TIME	0.83 HR	N/A	N/A
COMPUTER UNITS	19.4 VRU	N/A	N/A
COST	$194	N/A	N/A
COST-EFFECTIVENESS	161 $HR	N/A	N/A
1.3 TOTALS			
TIME	2.98 HR	N/A	N/A

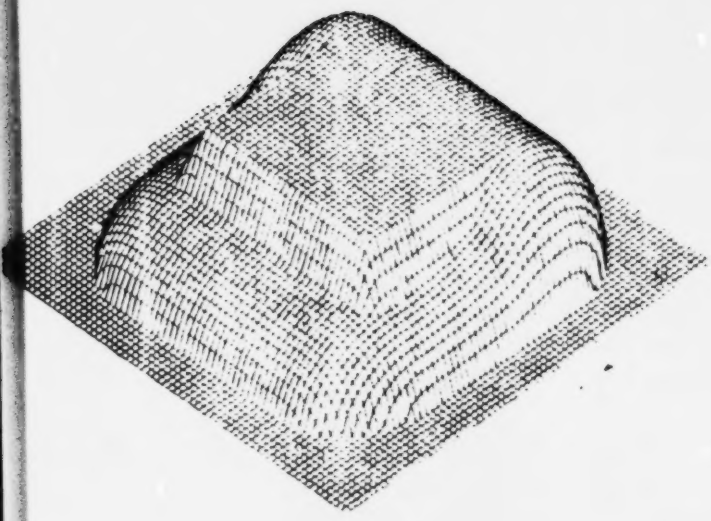
COMPUTER UNITS	67.0 VRU	N/A	N/A
COST	$670	N/A	N/A
COST-EFFECTIVENESS	1997 $HR	N/A	N/A

---

2. DRAFTING PROBLEM			
2.1 GEOMETRY			
TIME	0.47 HR	1.27 HR	1:3
COMPUTER UNITS	10.0 VRU	329 SBU	N/A
COST	$100	$125	1:1.3
COST-EFFECTIVENESS	47 $HR	159 $HR	1:3.4
2.2 DRAFTING			
TIME	0 HR	3.08 HR	N/A
COMPUTER UNITS	0 VRU	1094 SBU	N/A
COST	N/A	$416	N/A
COST-EFFECTIVENESS	N/A	1280 $HR	N/A
GEOMETRY AND DRAFING COMBINED			
TIME	0.47 HR	4.35 HR	N/A
COMPUTER UNITS	10.0 VRU	1423 SBU	N/A
COST	$100	$540	1:5.4
COST-EFFECTIVENESS	47 $HR	2352 $HR	1:50
2.3 NC CURVE GENERATION AND TAPE PREPARATION			
TIME	1.57 HR	1.62 HR	1:1.03
COMPUTER UNITS	38.9 VRU	266 SBU	N/A
COST-EFFECTIVENESS	610 $HR	163 $HR	3.7:1

2.4 TOTALS

TIME	2.04 HR	6.13 HR	1:3.0
COST	$489	$671	1:4.1
COST-EFFECTIVENESS	997 $HR	4113 $HR	1:4.1



HALF SECTION ELEMENTS

Four Planes
Two ellipsoids
Two elliptical cylinders
One variable elliptical cylinder
One cone

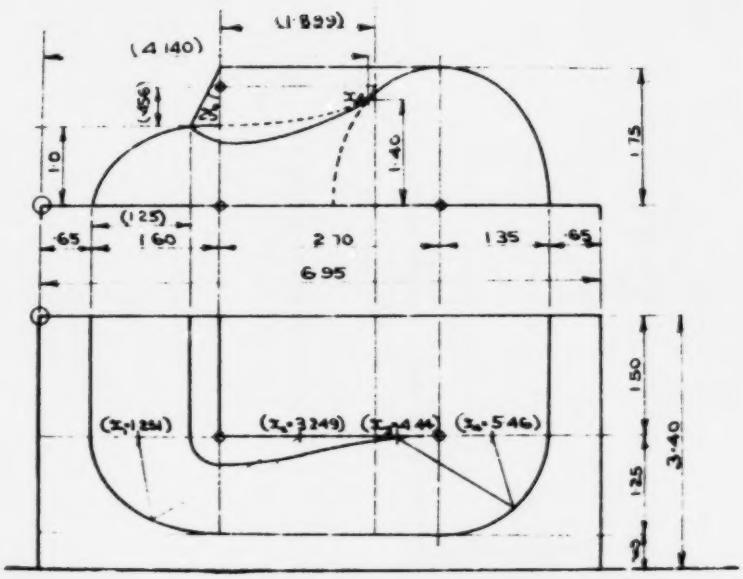


FIGURE 1.

Principal sections of a vacuum cleaner housing punch model, defined as elliptical curves in plan and elevation were spanned by computation of highest points over a fine grid of all surface elements existing at each base-grid point.

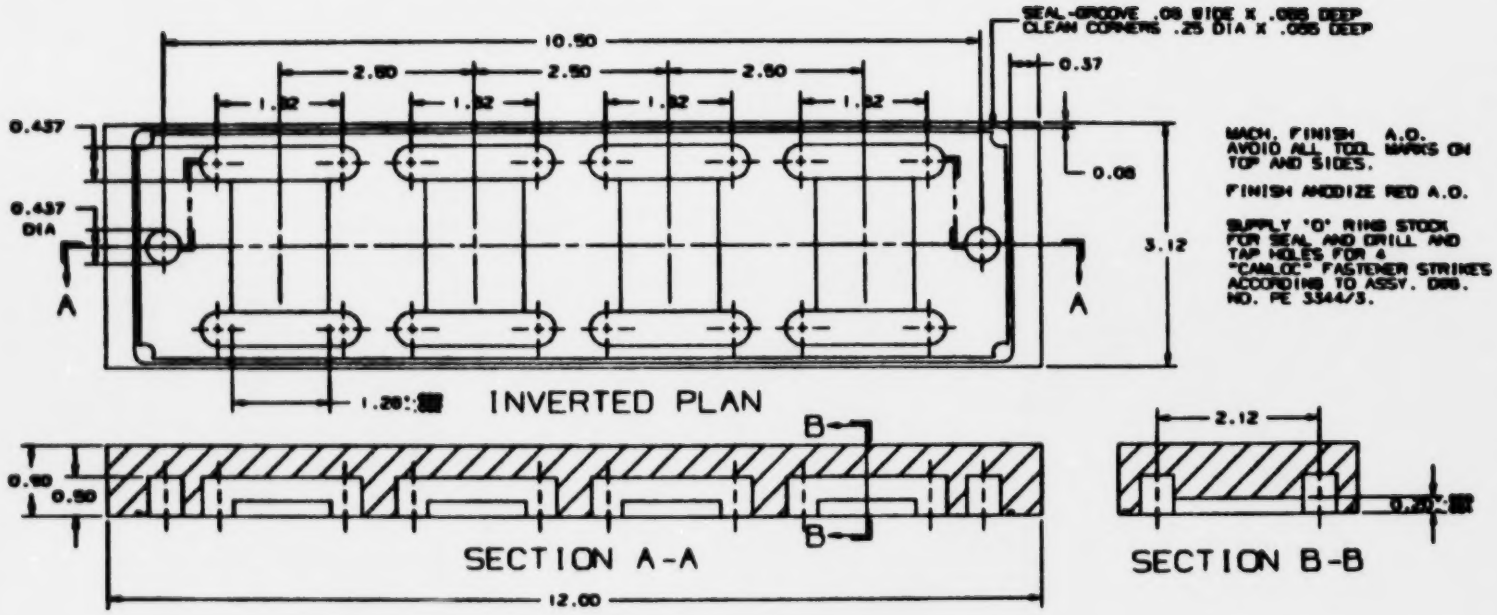


FIGURE 2.

DRAFTING PROBLEM

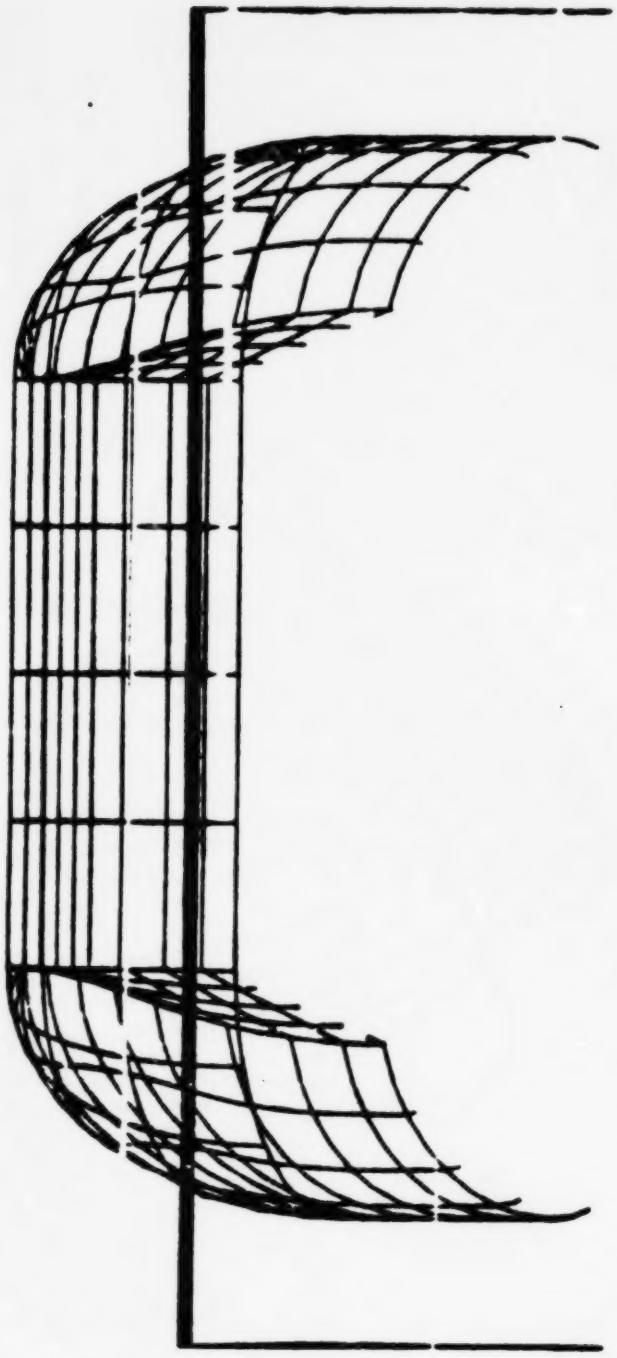
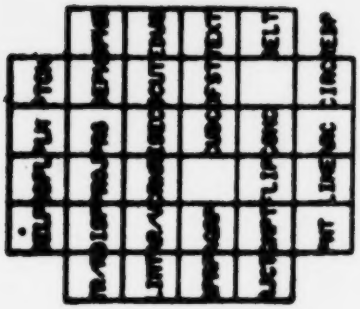
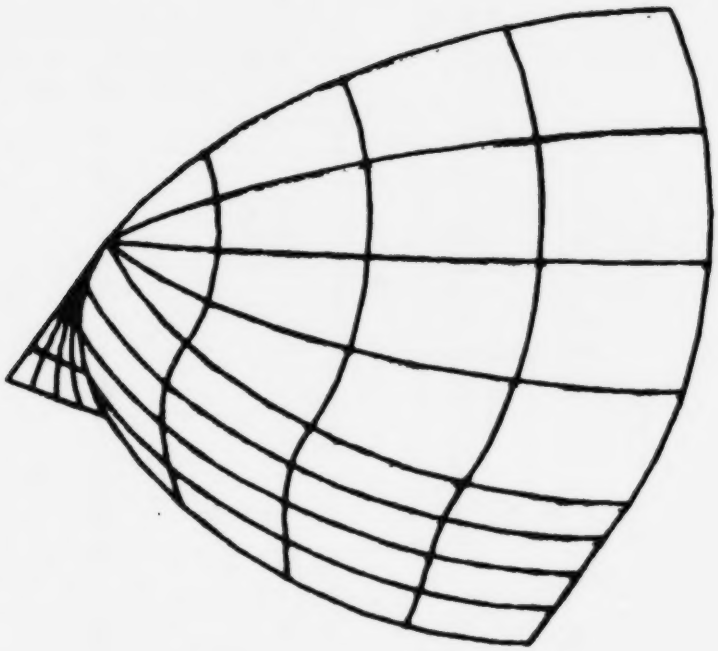
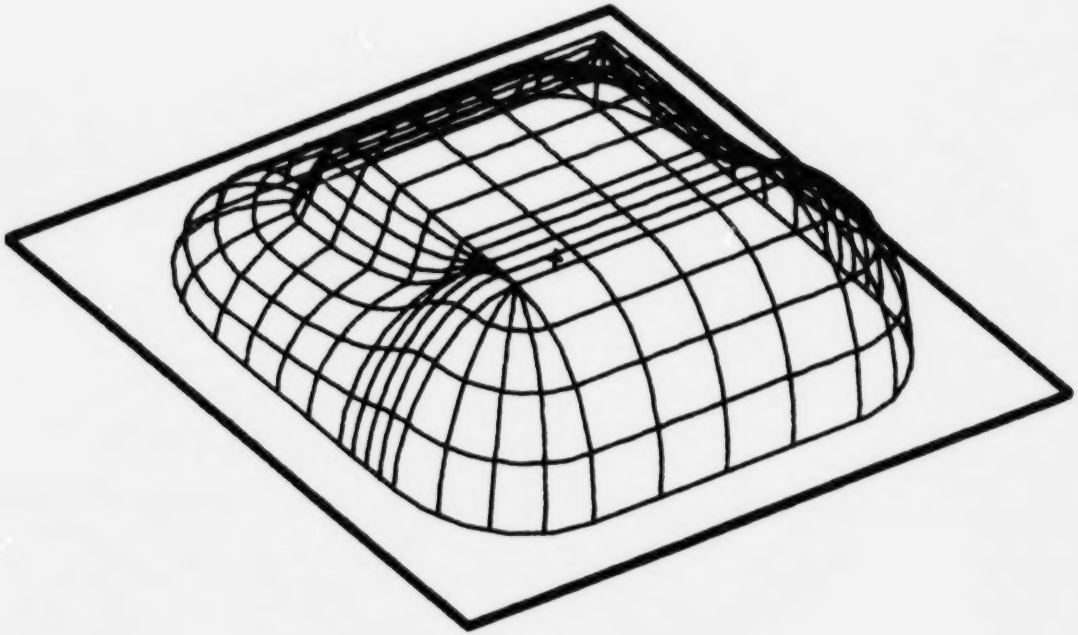


FIGURE 3.
COMPLEX CURVE PROBLEM - CADD DRAWING





COMPLEX CURVE PROBLEM - CADD
FIGURE 4.



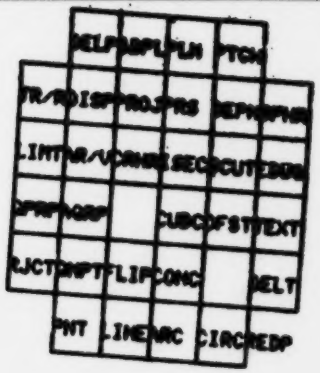
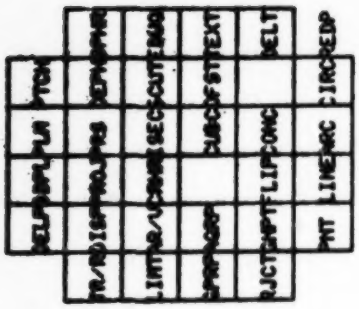


FIGURE 5.

COMPLEX CURVE PROBLEM - CADD DRAWING



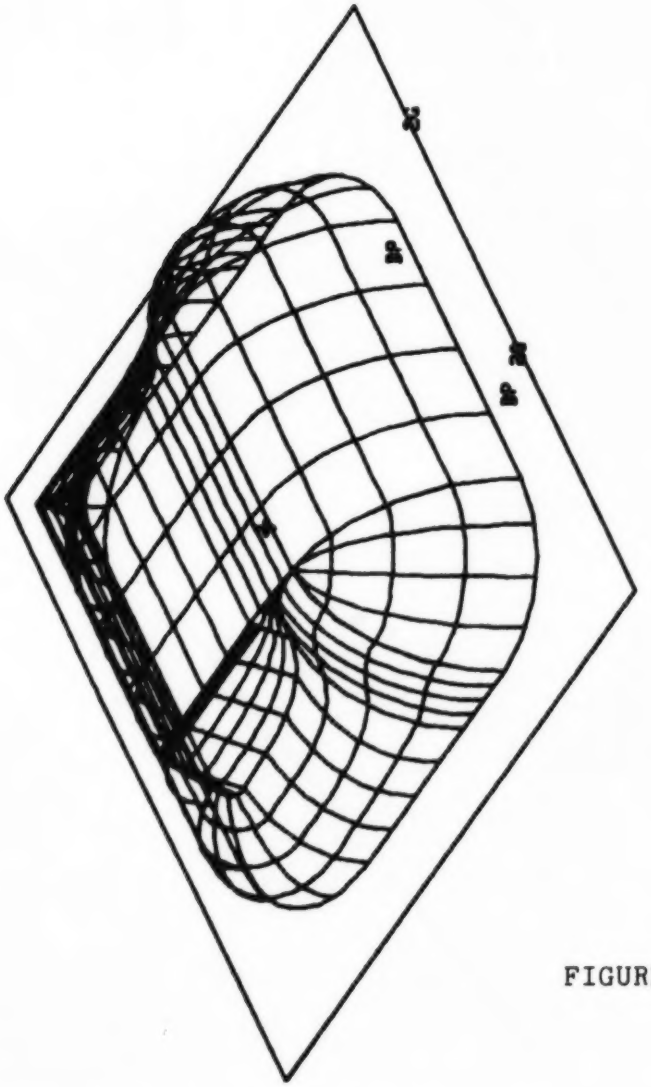
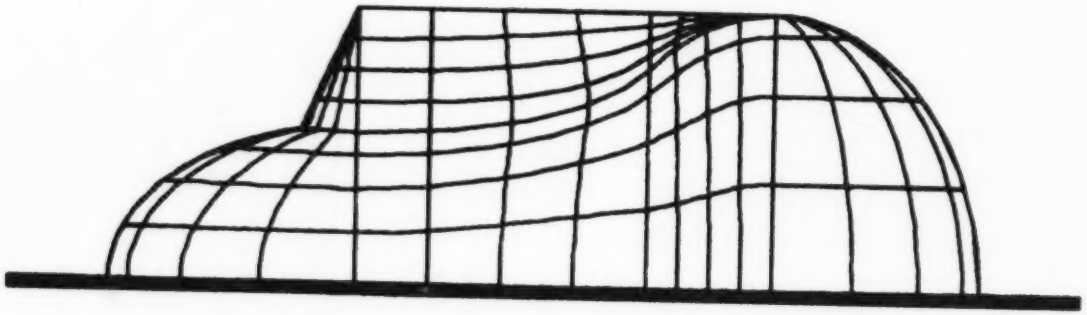


FIGURE 6.

COMPLEX CURVE PROBLEM - CADD DRAWING



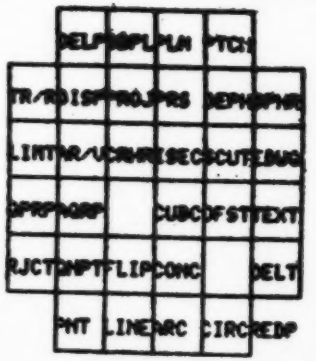
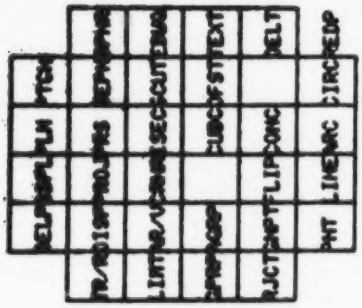


FIGURE 7.
COMPLEX CURVE PROBLEM - CADD DRAWING



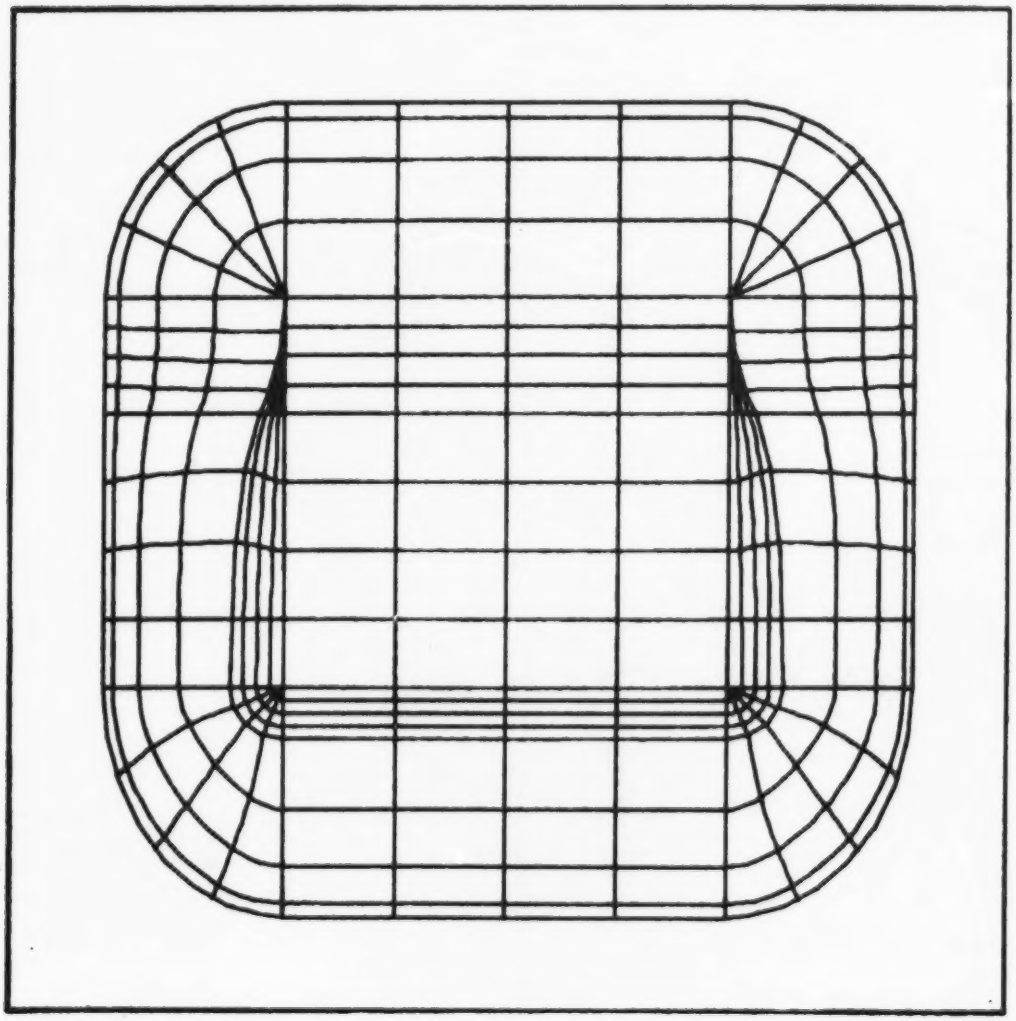
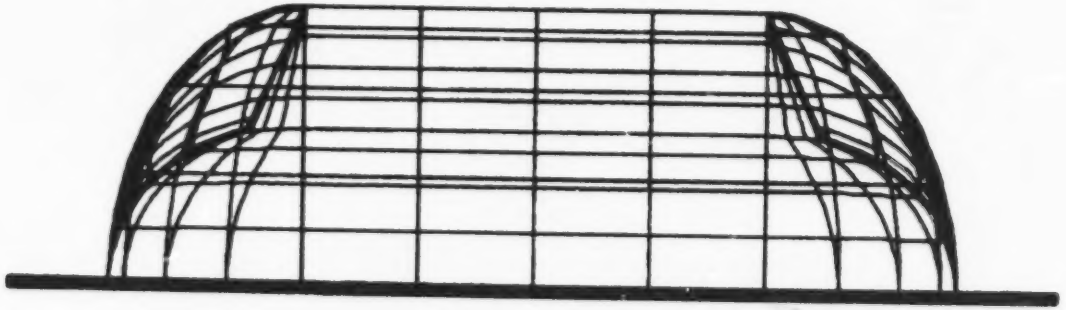


FIGURE 8.

COMPLEX CURVE PROBLEM - CADD DRAWING



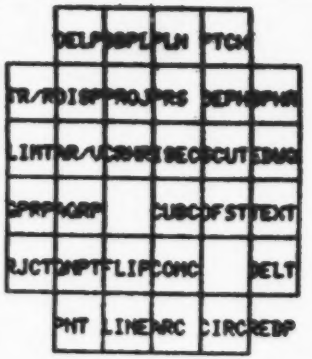
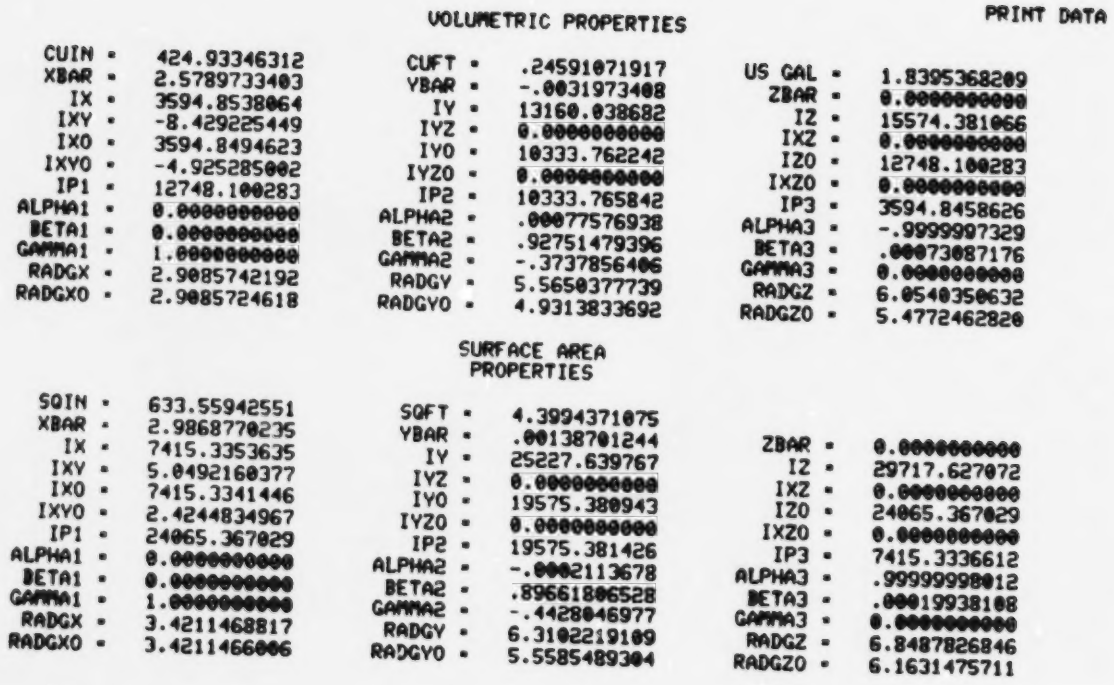


FIGURE 9.
COMPLEX CURVE PROBLEM - CADD DRAWING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IX = 3594.8538064
IXY = -8.429225449
IXO = 3594.8494623
IXYO = -4.925285002
IP1 = 12748.100283
ALPHA1 = 0.0000000000
BETA1 = 0.0000000000
GAMMA1 = 1.0000000000
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RADGXO = 2.9085724618
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YBAR = -.0031973408
IY = 13160.038682
IYZ = 0.0000000000
IYO = 10333.762242
IYZO = 0.0000000000
IP2 = 10333.765842
ALPHA2 = .00077576938
BETA2 = .92751479396
GAMMA2 = -.3737856406
RADGY = 5.5650377739
RADGYO = 4.9313833692
US GAL = 1.8395368209
ZBAR = 0.0000000000
IZ = 15574.381066
IXZ = 0.0000000000
IZO = 12748.100283
IXZO = 0.0000000000
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ALPHA3 = -.9999997329
BETA3 = .00073087176
GAMMA3 = 0.0000000000
RADGZ = 6.0540350632
RADGZO = 5.4772462820
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IXY = 5.0492160377
IXO = 7415.3341446
IXYO = 2.4244834967
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ALPHA1 = 0.0000000000
BETA1 = 0.0000000000
GAMMA1 = 1.0000000000
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RADGXO = 3.4211466006
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IZO = 24065.367029
IXZO = 0.0000000000
IP3 = 7415.3336612
ALPHA3 = .99999998012
BETA3 = .00019938188
GAMMA3 = 0.0000000000
RADGZ = 6.8487826846
RADGZO = 6.1631475711
COMPLEX CURVE PROBLEM - CADD DRAWING
EXIT

FIGURE 10.

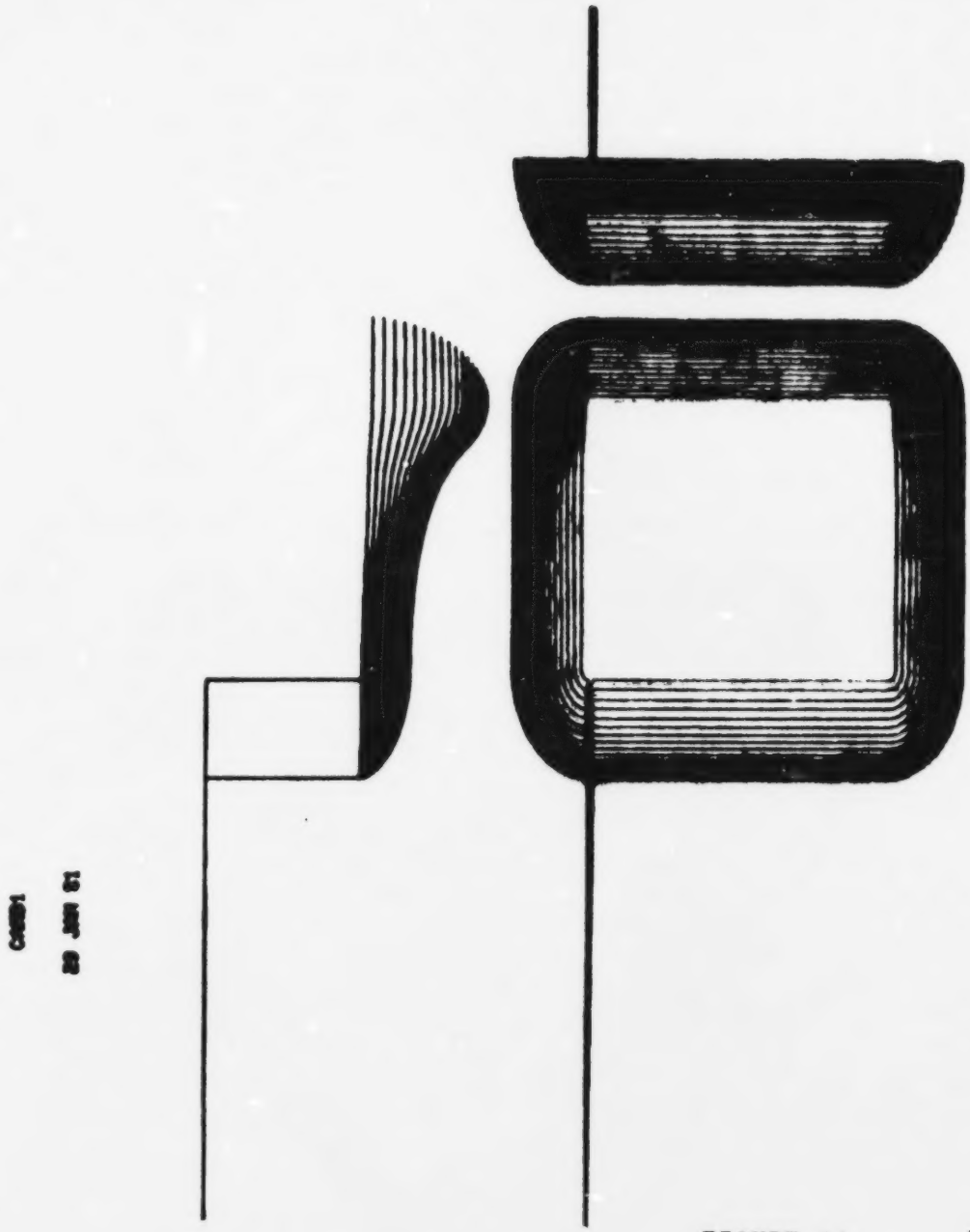
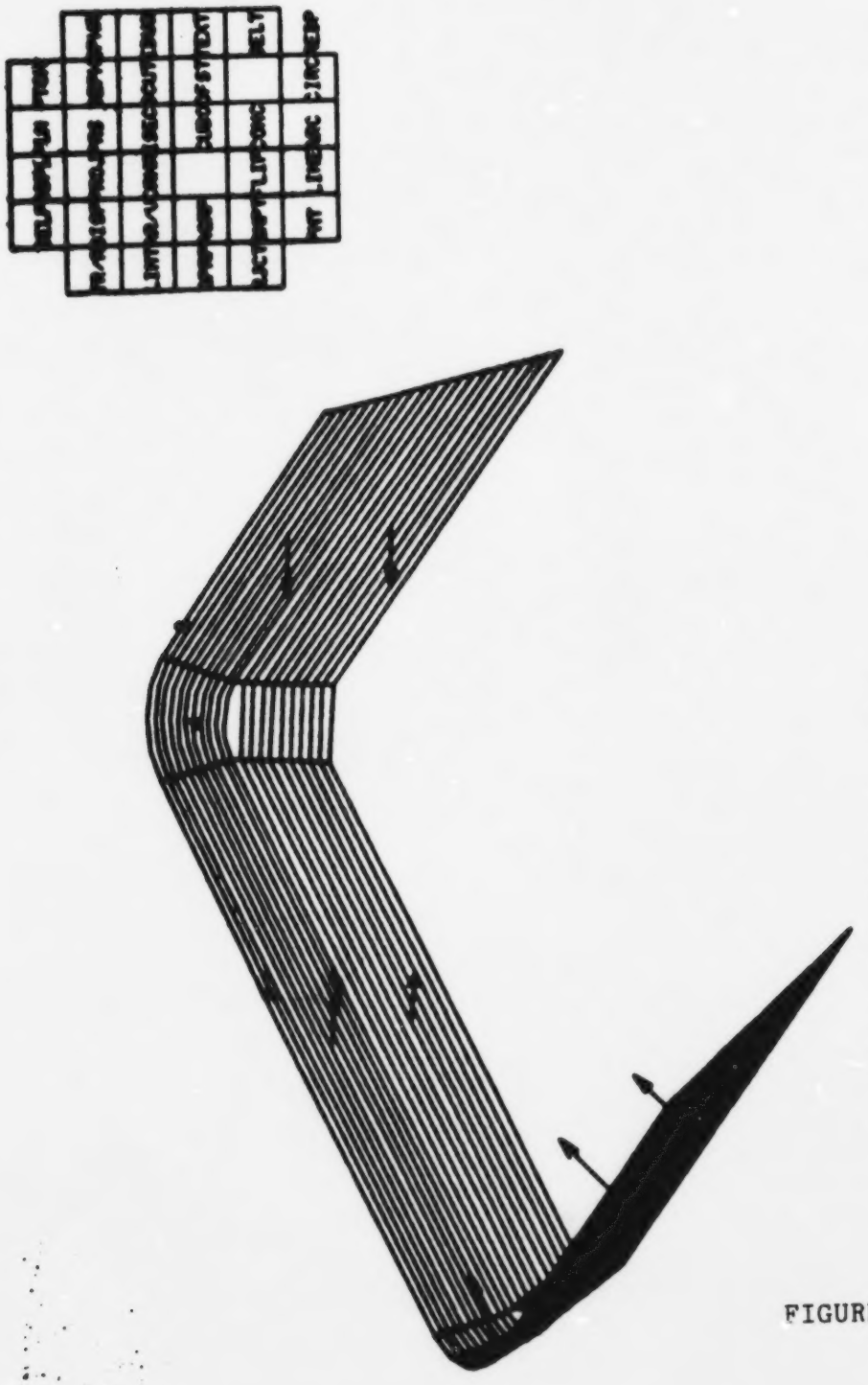


FIGURE 11.

COMPLEX CURVE PROBLEM - CADD DRAWING
DIAGRAM OF NC PATHS



COMPLEX CURVE PROBLEM - CADD
DIAGRAM OF NC PATHS

FIGURE 12.

FIGURE 13.

COMPLEX CURVE PROBLEM - CD/2000

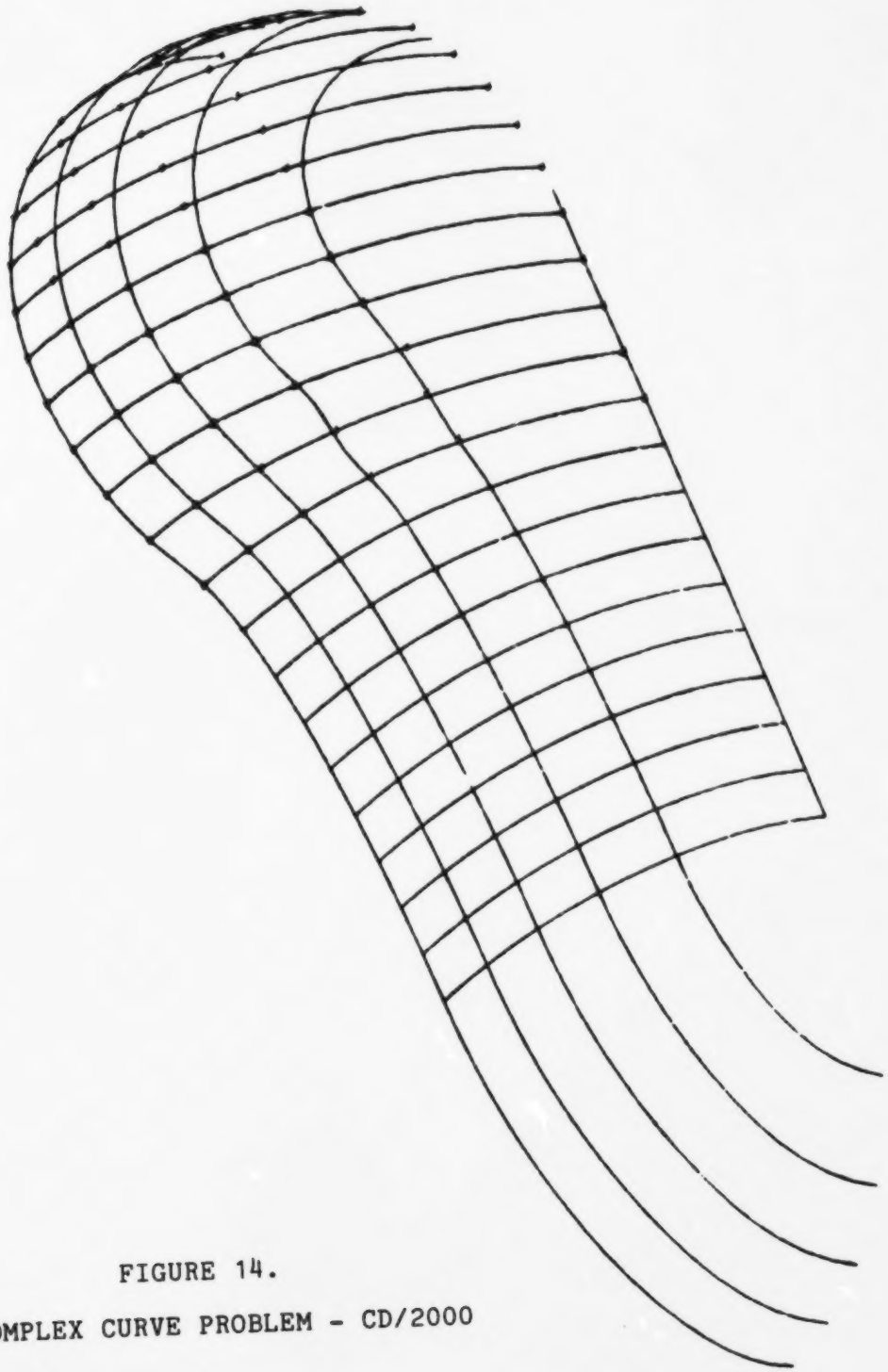


FIGURE 14.

COMPLEX CURVE PROBLEM - CD/2000

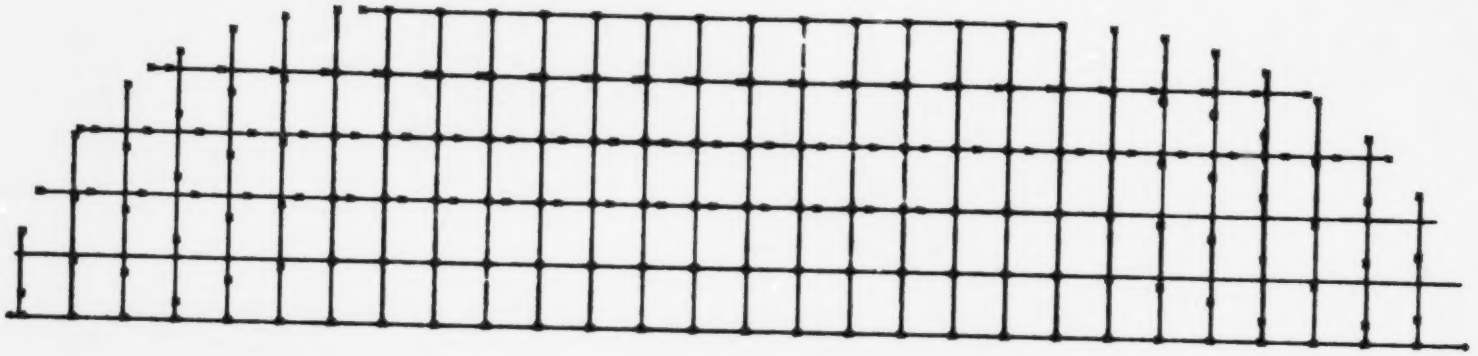


FIGURE 15.

COMPLEX CURVE PROBLEM - CD/2000

DRAFTING PROBLEM - CADD

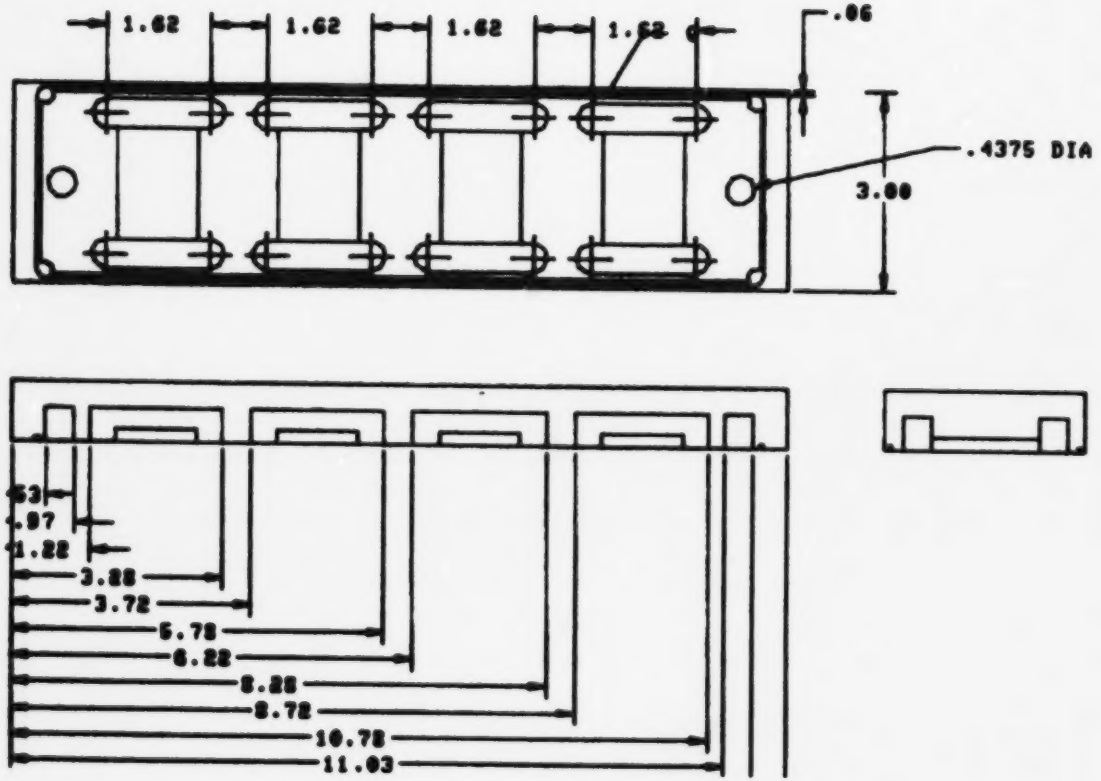


FIGURE 16.

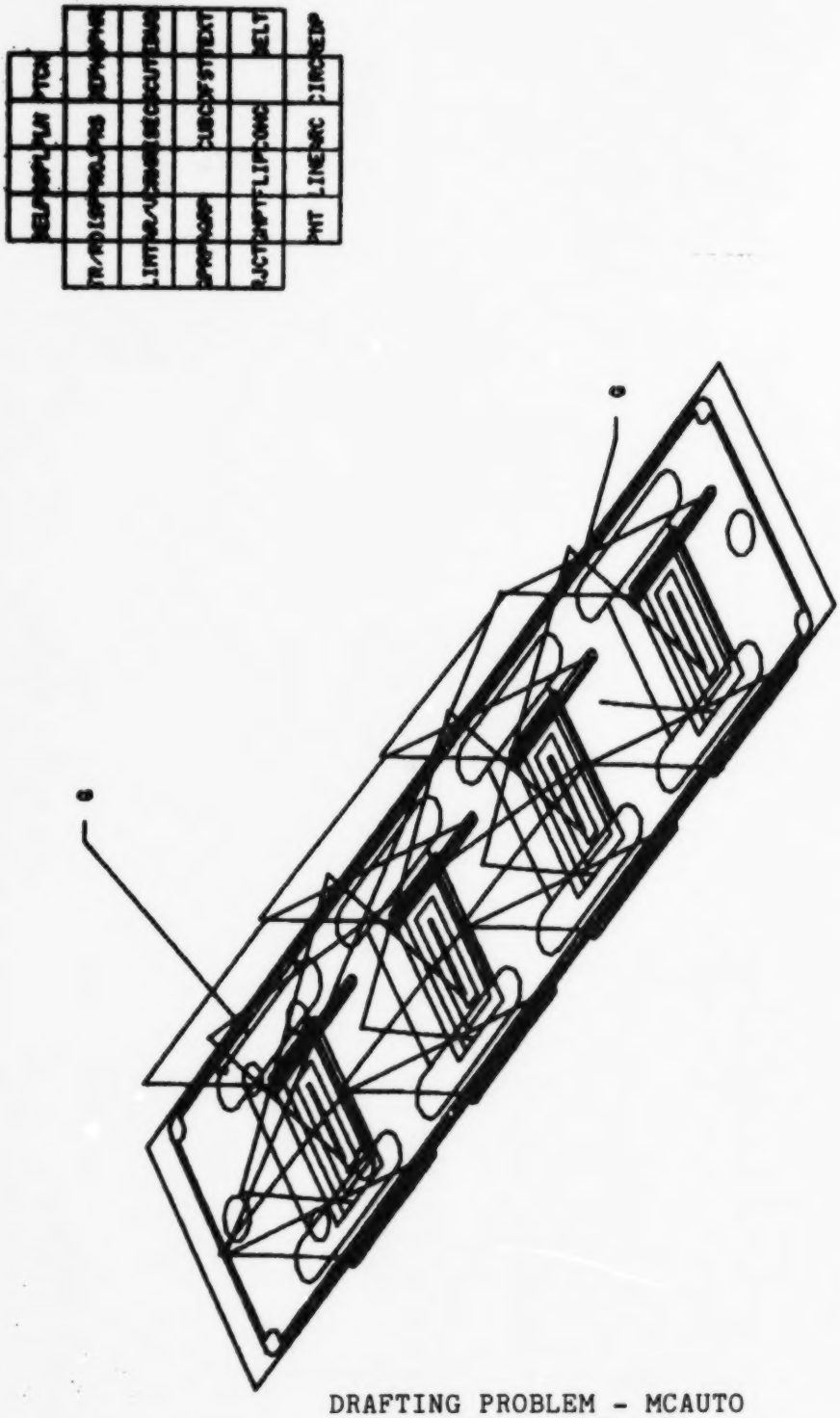


FIGURE 17.

DRAFTING PROBLEM - MCAUTO
NC PATHS DISPLAYED

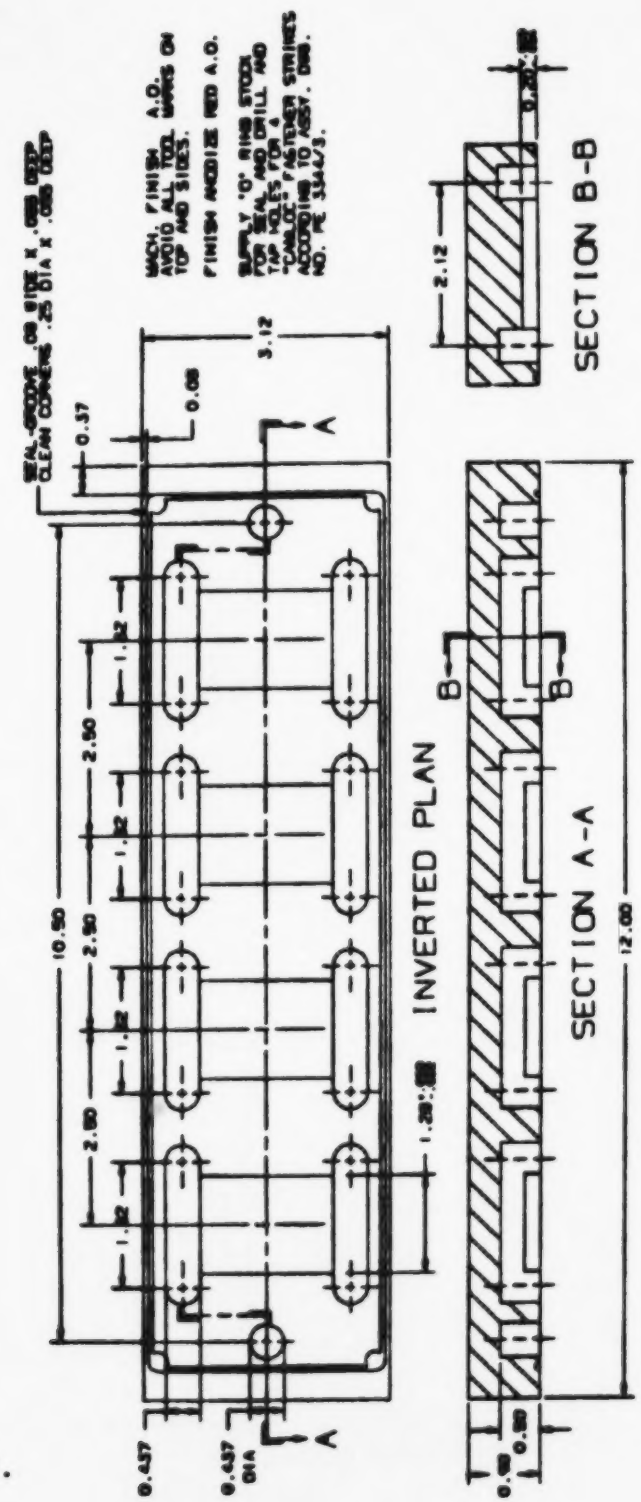


FIGURE 18. DRAFTING PROBLEM - CONTROL DATA

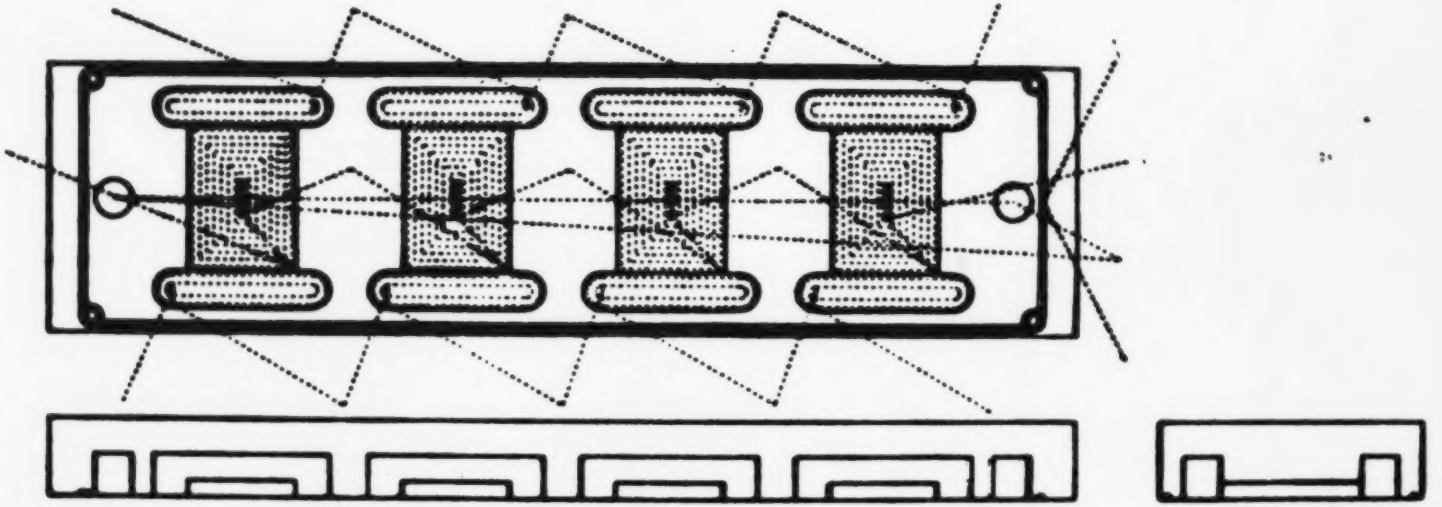


FIGURE 19.
DRAFTING PROBLEM - CONTROL DATA
NC PATHS DISPLAYED

METHODS OF ACCESSING MCAUTO CAD/CAM.

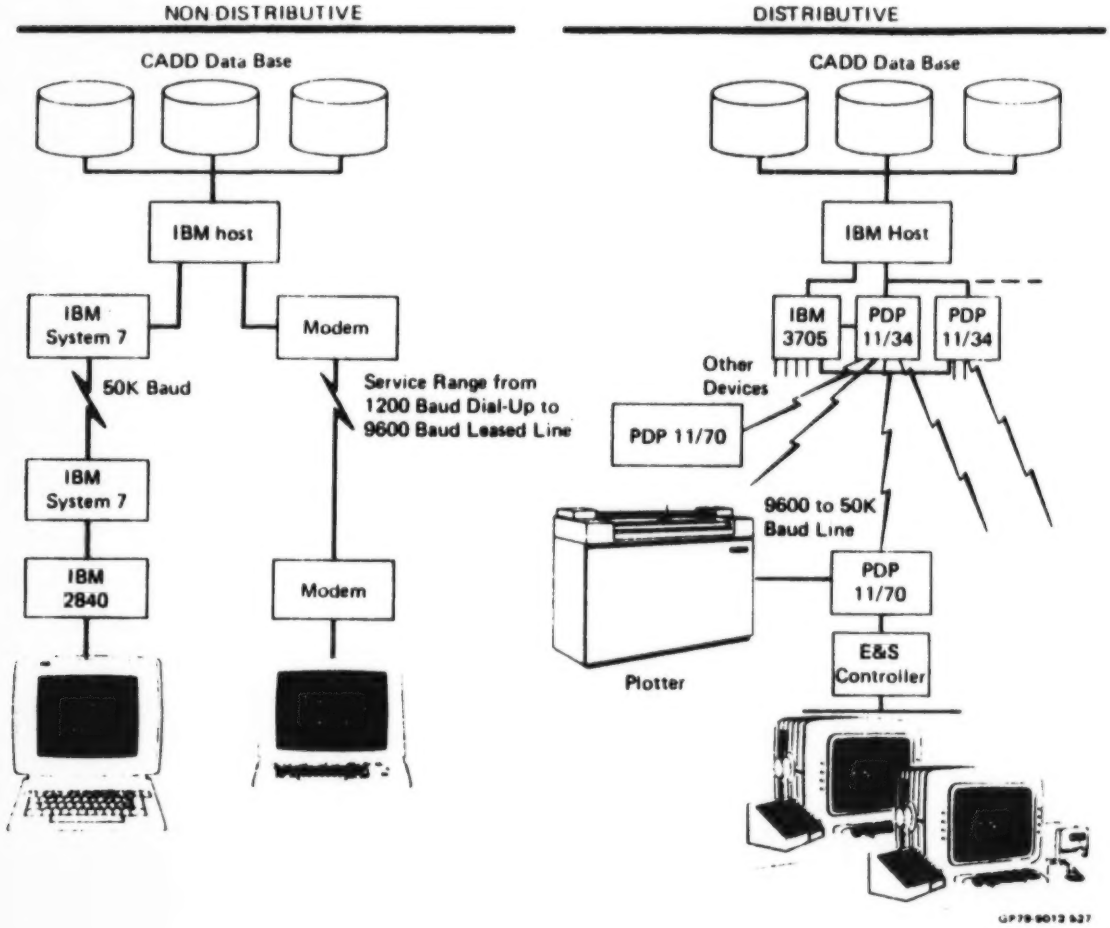


FIGURE 20.
BLOCK DIAGRAM OF MCAUTO CAD/CAM

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D
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OTTAWA, ONTARIO K1O 0Z4

2a. DOCUMENT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. DOCUMENT TITLE
COMPUTER-AIDED DESIGN AT DEFENCE RESEARCH ESTABLISHMENT OTTAWA

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Note

5. AUTHOR(S) (Last name, first name, middle initial)
HIDSON D.J.

6. DOCUMENT DATE
MARCH 1982

7a. TOTAL NO. OF PAGES
42

7b. NO. OF REFS
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8a. PROJECT OR GRANT NO.
13B

8b. CONTRACT NO.

9a. ORIGINATOR'S DOCUMENT NUMBER(S)
DREO TN 82 - 17

9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

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11. SUPPLEMENTARY NOTES

12. SPONSORING ACTIVITY

13. ABSTRACT

This paper describes the specifications for a computer-aided design and computer-aided manufacturing (CAD/CAM) system. A series of benchmark tests were performed with various vendors and on the basis of these results a system is recommended.

DSIS
77-065

Security Classification

KEY WORDS

- COMPUTER-AIDED DESIGN
- CAD/CAM
- COMPUTER-AIDED ENGINEERING
- COMPUTER GRAPHICS

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